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PHYSICAL TESTING FOR THE MICROGRAVITY PLANT NUTRIENT EXPERIMENT

by

T. W. Dreschel, C. W. Carlson,
H. W. Wells, K. F. Anderson.
The Bionetics Corporation

W. M. Knott and W. Munsey
The National Aeronautics and Space Administration

J. F. Kennedy Space Center, FL 32899

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SUMMARY:

The Microgravity Plant Nutrient Experiment (MPNE) is a Space Shuttle middeck locker hardware test to verify the operation of a hydroponic system devised for microgravity called the Porous Tube Plant Nutrient Delivery System. Physical tests of the system under various accelerations on the NASA KC-135 have been successful.

KEYWORDS:

Hydroponics, Space program, Technology.

American Society of Agricultural Engineers
2950 Niles Road, St. Joseph, Michigan 49085-9659 USA
Voice: 616.429.0300 FAX: 616.429.3852

CSAE SCGR

Introduction:

NASA's Controlled Ecological Life Support System (CELSS) Program centers on using crop plants to recycle air and water and produce food for long-term space exploration. The CELSS Test Facility (CTF) is a plant research facility being planned for Space Station Freedom. The design and implementation of the CTF is dependent on the development of critical technologies such as atmospheric concentrations control, water (condensate) recovery and plant water and nutrient delivery.

The Microgravity Plant Nutrient Experiment (MPNE) is a CTF Critical Technology flight test to verify the operation of a hydroponic system devised for microgravity. The system is called the Porous Tube Plant Nutrient Delivery System. This experiment involves the development of experimental hardware for the Space Shuttle middeck and a flight experiment to perform functional verification in space. Previous works indicate that in microgravity, the capillary and surface tension forces predominate (Tsao et al., 1993; Finger, 1992). To determine the effects of these forces on specific nutrient delivery systems, testing was performed under varying acceleration conditions during parabolic flight on the NASA KC-135 aircraft (JSC, 1991; Walker et al., 1992). A typical parabolic profile is shown in Figure 1. Three fluid loop Test Bed Units or TBUs (Figure 2) were flown to test the physical operation of the Porous Tube

Figure 1. A parabolic profile from the NASA KC-135 (from the JSC KC-135 Users Manual, Appendix E, P. E-1).

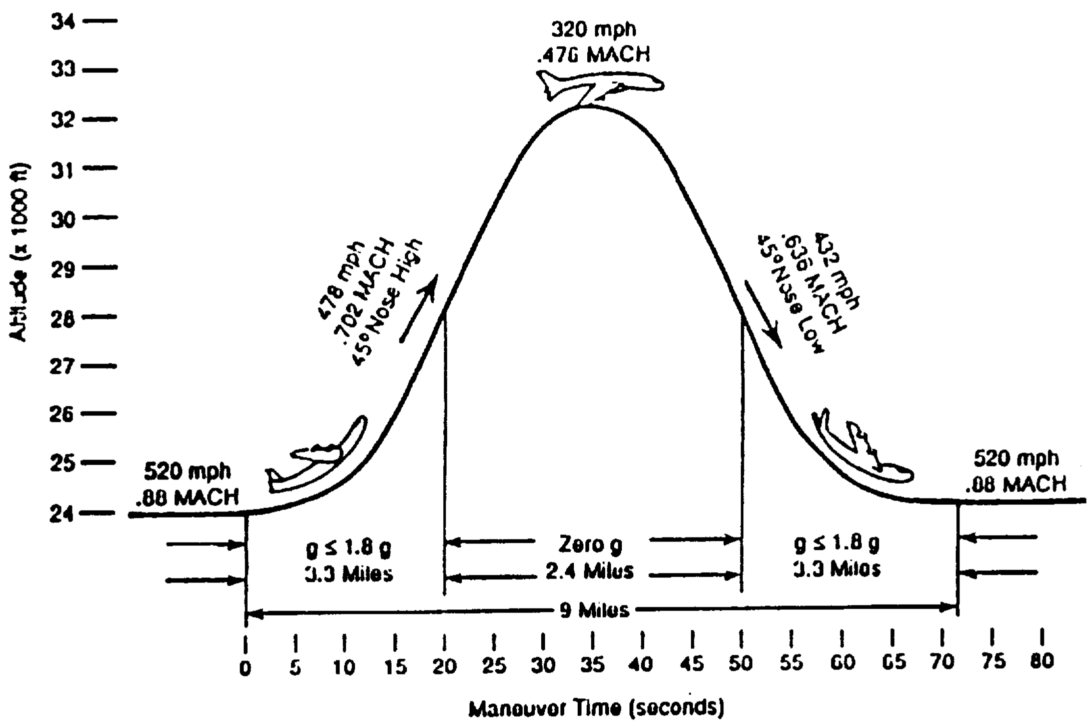
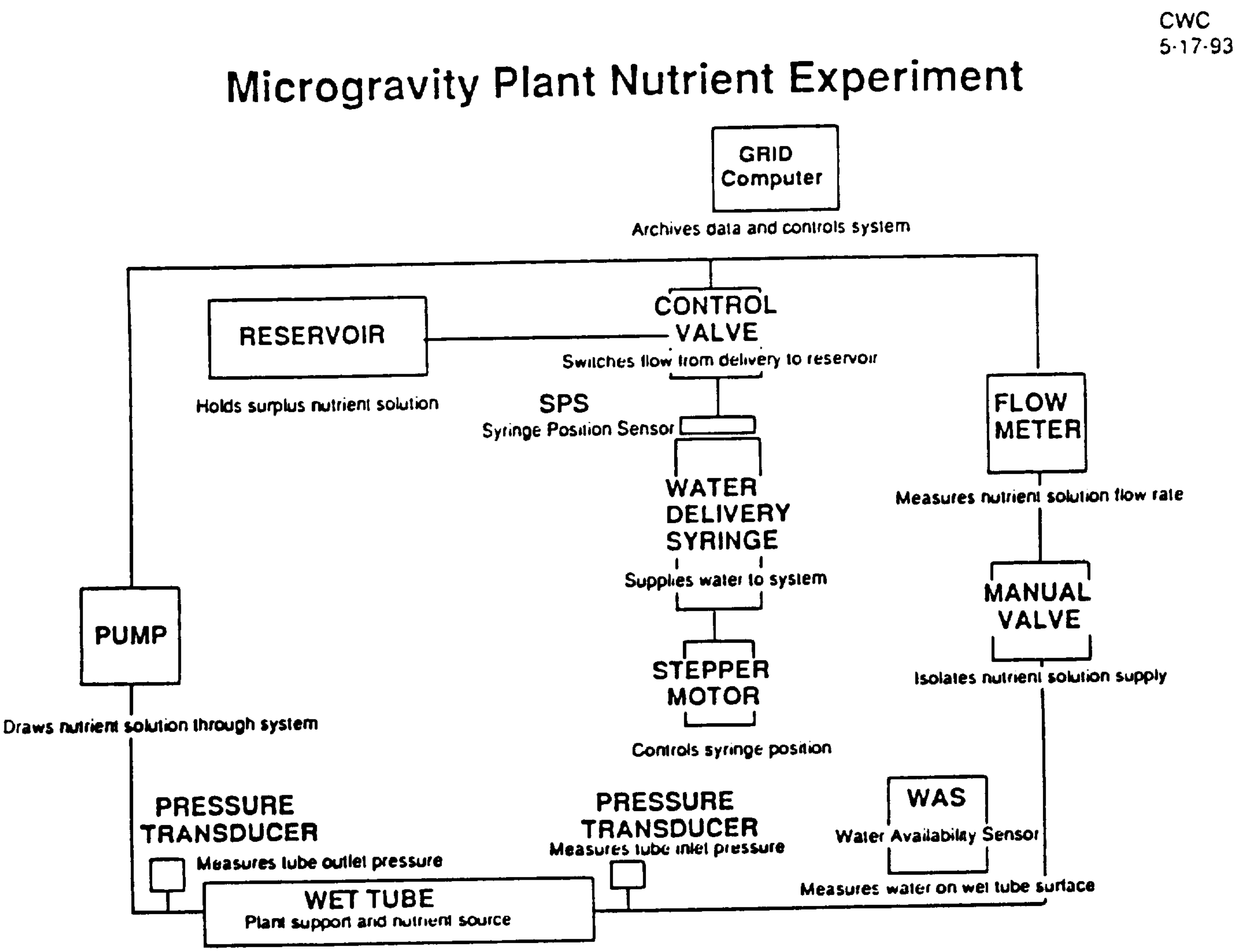


Figure 2. Schematic diagram of one of the Porous Tube Plant Nutrient Delivery System Test Bed Units (TBU).



Plant Nutrient Delivery System or PTPNDS (Dreschel and Sager, 1989; Dreschel, 1990; Dreschel, 1992; Dreschel, 1992a; Dreschel, 1992b; Dreschel and Brown, 1993; Dreschel et al., 1993) under various acceleration environments, specifically controlling the wetting of the surface of the porous tube. These TBUs contained a PTPNDS including a porous ceramic delivery tube, pump, fluid loop, syringe pump, reservoir syringe, and various sensors. The TBUs were computer controlled and each contained a ceramic tube of a different pore size (0.3, 0.7 and 2.0 micrometer). Also flown on the KC-135 was a glovebox in which various prototype devices for plant nutrient solution delivery were operated and observed. These were porous tubes, aeroponic and flow-through hydroponic systems and a device using porous teflon tubing for removing bubbles from water.

Characterizing the acceleration environment on the NASA KC-135 aircraft:

Three sorties were flown and a three-axis accelerometer (XYZ) was included in the TBU package. Acceleration is measured relative to earth normal gravity (1.0 g). Examples of first day parabolas are shown in Figure 3, which include zero-g, simulated Lunar (one-sixth g at about 125 seconds) and Mars gravities (one-third g at about 750 seconds) and the approximately 1.8 g which is provided by the acceleration into the parabola. The zero-g environment, which lasts approximately 15 seconds (Figure 4) varies

Figure 3. Example plot of acceleration versus time for the MPNE tests on the KC-135.

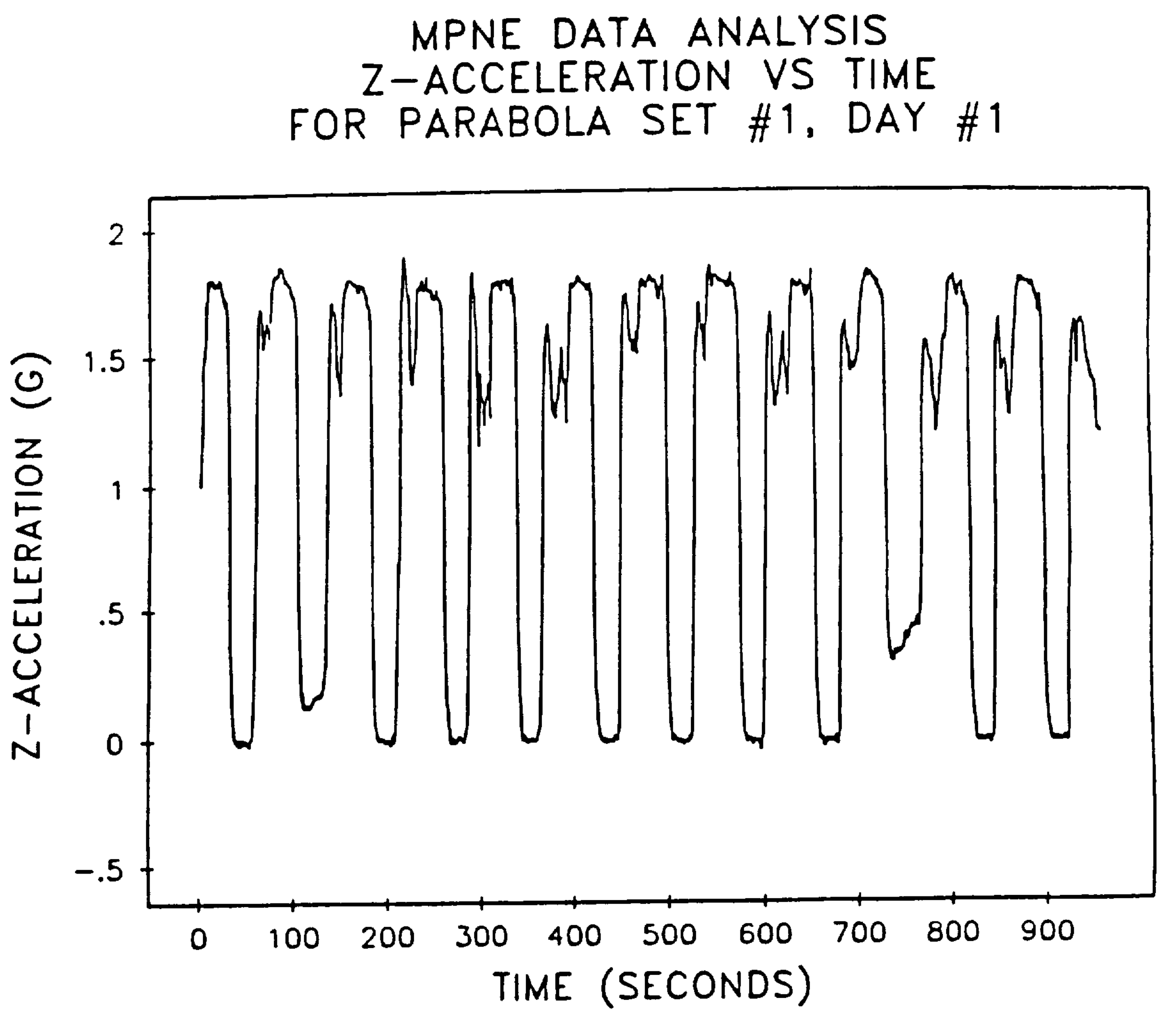
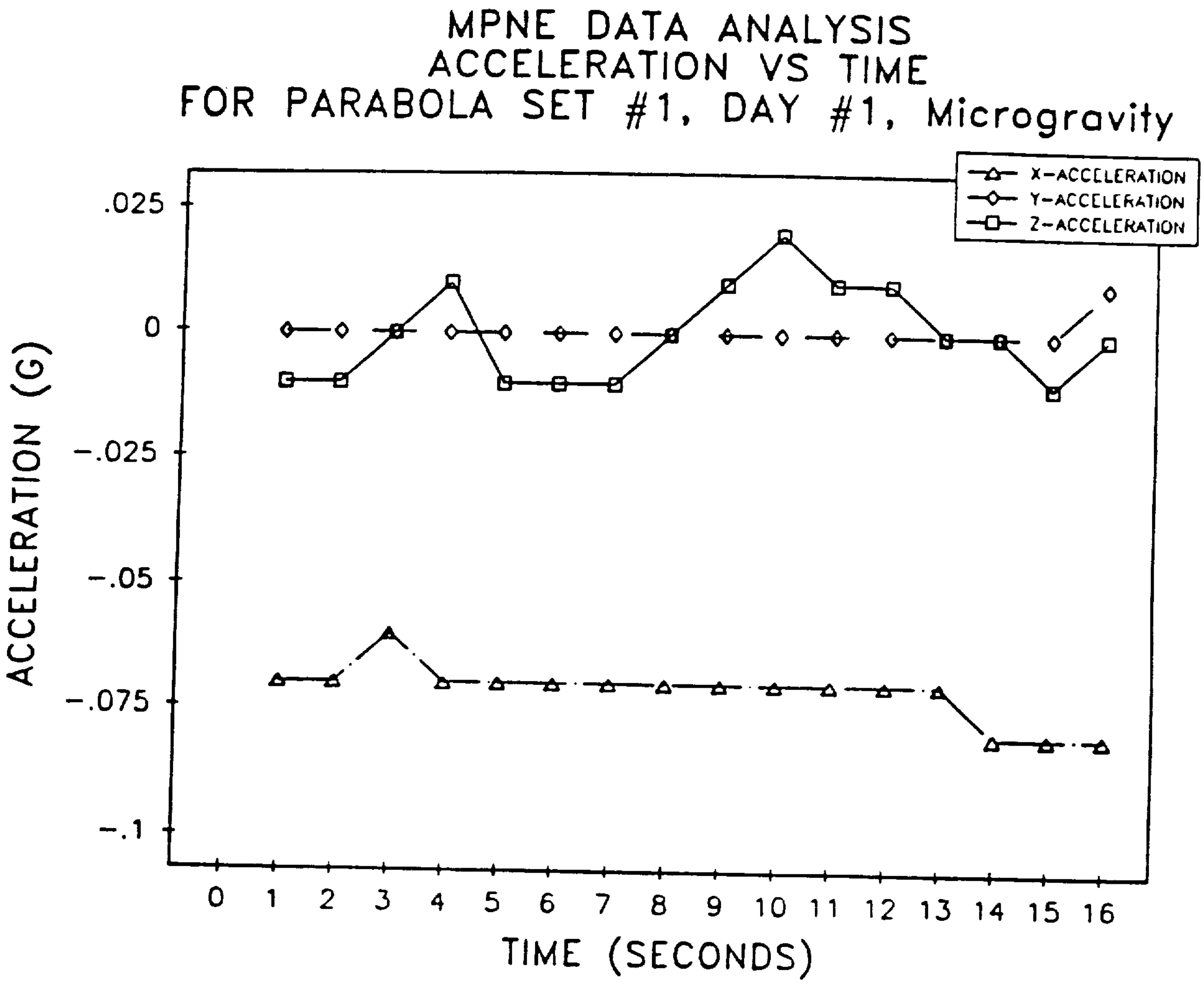


Figure 4. An example of microgravity acceleration versus time experienced on the KC-135.



between -.02 and +.05 g in the Z direction, is slightly negative in the X direction (-0.05 g) and is zero or slightly negative (-0.01 g) in the Y direction. A simulated lunar acceleration environment which lasts about 20 seconds (Figure 5), varies between .14 and .21 g (Z direction) and is similar to the zero-g environment in the X and Y directions. The simulated Mars acceleration lasted about 30 seconds per parabola (Figure 6). This was between 0.27 and 0.44 g (Z direction) and again similar to the zero-g environment in the X and Y directions.

Although the various gravity environments are not sufficiently long or uniformly constant on the KC-135 for examining the response of biological systems to each acceleration environment, there is ample time to make valuable observations and perform dynamic physical experiments or tests on spaceflight hardware.

Evaluating the Porous Tube Plant Nutrient Delivery System response to various acceleration environments:
The ceramic tubes used in the TBUs are conventional porous ceramic filters (Osmonics, Inc., Minnetonka, MN)* which serve as a capillary interface between nutrient solution and plant roots, allowing the fine control of solution supplied

**The use of a brand name does not imply endorsement by NASA or The Bionetics Corporation.*

Figure 5. An example of Lunar gravity acceleration versus time experienced on the KC-135.

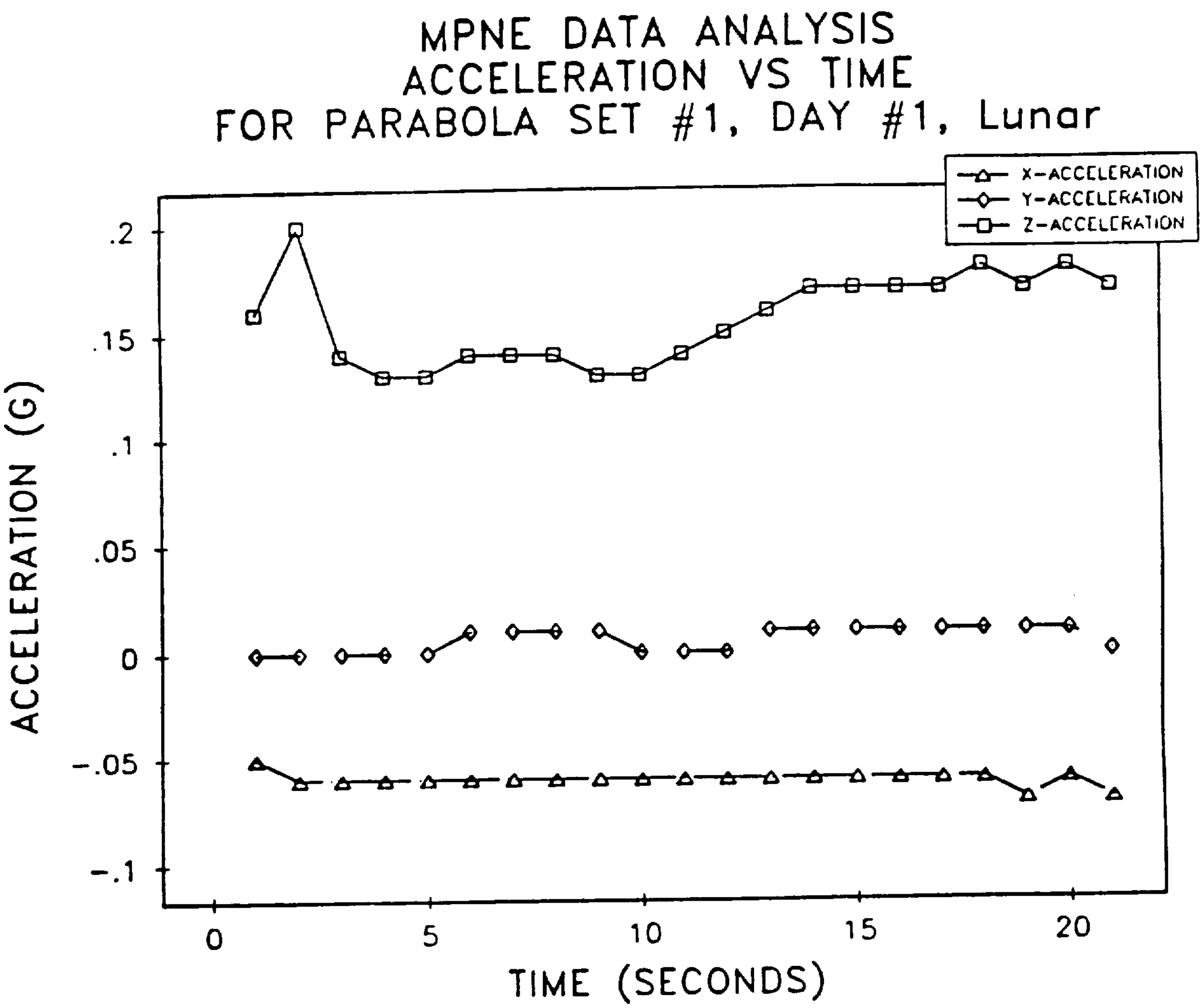
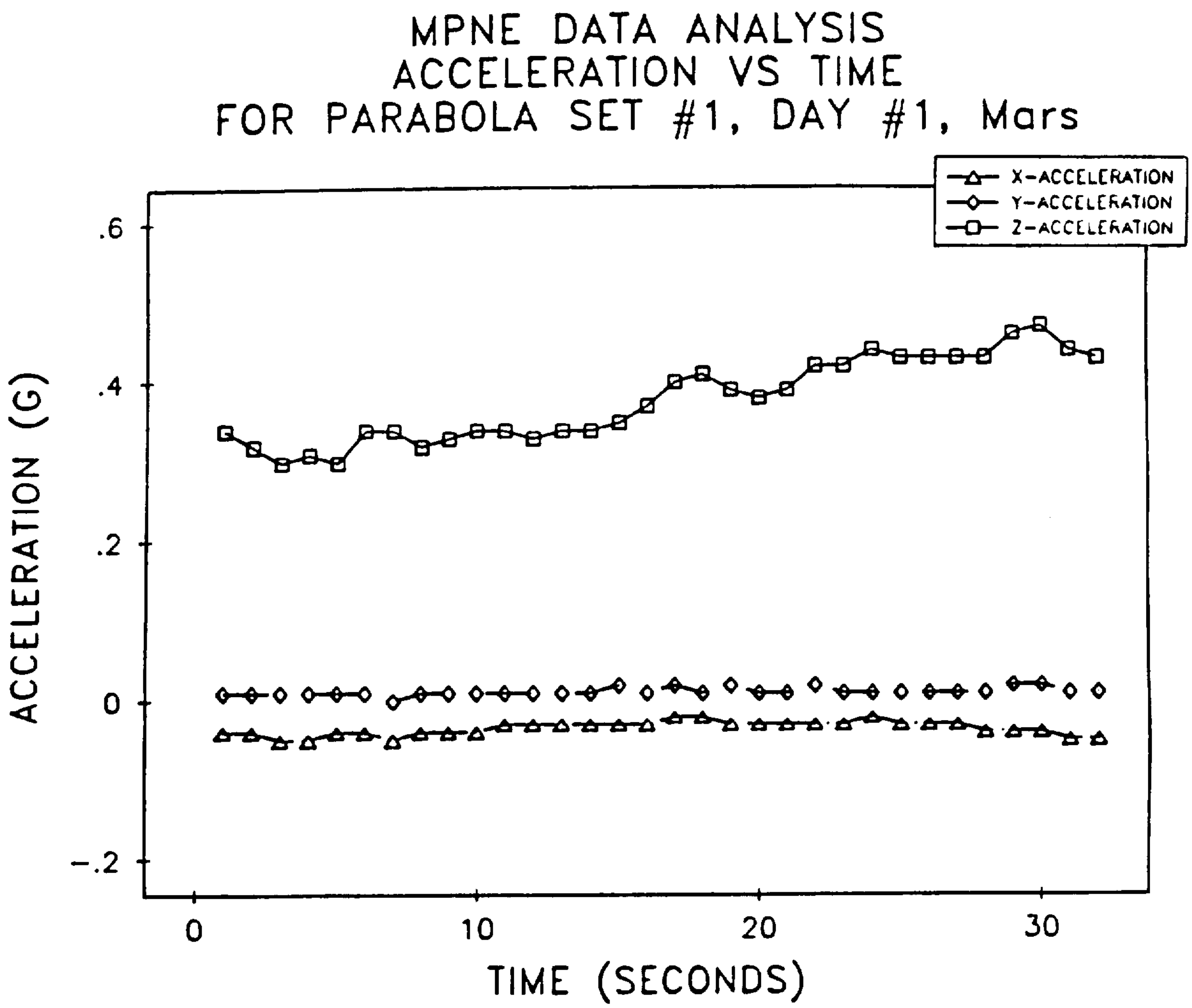


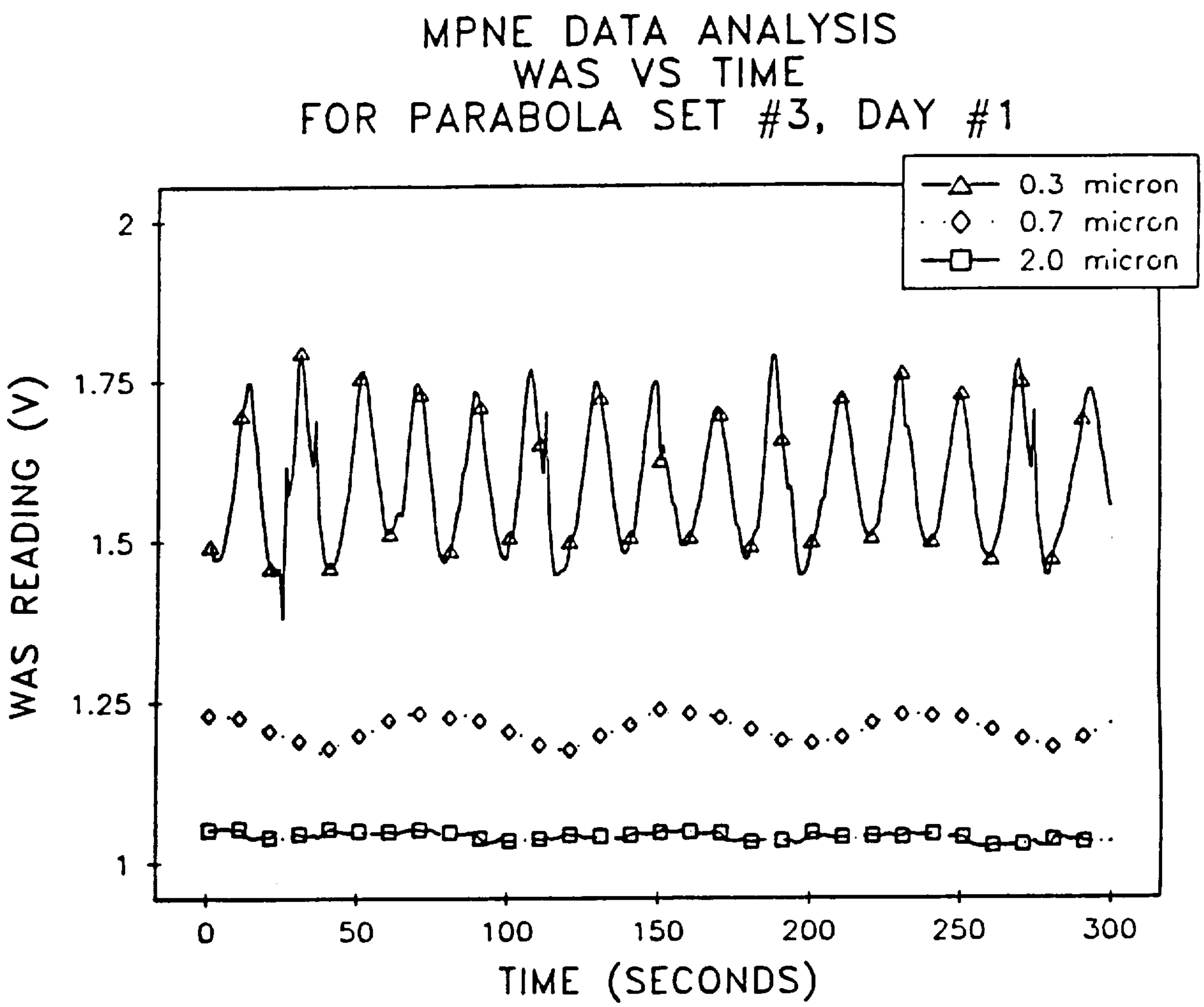
Figure 6. An example of Mars gravity acceleration versus time experienced on the KC-135.



to the roots (Dreschel, 1990, Dreschel et al., 1992, Dreschel et al., 1992a, Dreschel et al., 1992b). Surface wetness was measured and controlled using an infrared Water Availability Sensor or WAS (Developed by The Bionetics Corporation and built by Boeing, Kennedy Space Center, FL)*, with Optoware (Opto 22, Huntington Beach, CA)* analog to digital interface equipment and a laptop computer. The surface wetness of the porous tube decreased the infrared reflectance as measured by the WAS and therefore provided a negatively correlated signal for control. The control of surface wetness was facilitated by a stepper motor operated syringe pump which could add or remove water from the fluid loop when required.

The three TBUs were flown for the three sorties, a total of 147 parabolas over two days. During the first sortie, the computer was programmed to control the WAS readings to a single set point for each TBU. During the second and third sorties, the computer was programmed to control the WAS readings dependent on acceleration by adding or removing water from the fluid loop via the syringe pump. Initial set points were determined during laboratory testing of the TBUs and adjusted as needed during the sorties. During the sorties, the WAS operated as expected and the surface wetness of the tubes was dependent on pore size, control algorithms, and acceleration (Figure 7). The ability to control the surface wetness decreased with decreasing pore

Figure 7. Examples of Water Availability Sensor readings versus time with control to a single set-point.



size as acceleration changed, thus the smallest pore size tube responded slowly and did not allow the control dynamics obtained with the other tubes. A similar pattern was seen when controlling setpoint to acceleration (Figure 8). Response time increased with decreasing pore size, giving overall greater variability.

The amount of water added to the fluid loop by the syringe pump was measured by a Syringe Position Sensor (SPS). A 0.01 volt increase in SPS readings corresponded to a 11.56 microliter addition of water to the fluid loop. A linear relationship was demonstrated between the WAS voltage and the amount of water (from SPS readings) added to attain the readings during a number of parabolas, especially from the 0.7 micron pore size TBU (Figure 9). This relationship was verified in the laboratory (constant 1-g) by injecting appropriate volumes of water into a sealed tube and making WAS measurements (Figure 10). The linear relationship seen on the KC-135 indicates a rapid and linear response of the hardware to the changes in acceleration experienced during the parabolas. As with the laboratory measurements, it demonstrates a similar response of the surface moisture on the porous tube in varying gravities and at a constant one gravity. This linear relationship was most commonly seen during the change from 1.8-g to micro-g and much less common during the micro-g to 1.8-g segment of the parabola. This relationship demonstrates the sensitivity of the WAS as a

Figure 8. Examples of Water Availability Sensor readings versus time with acceleration dependent control.

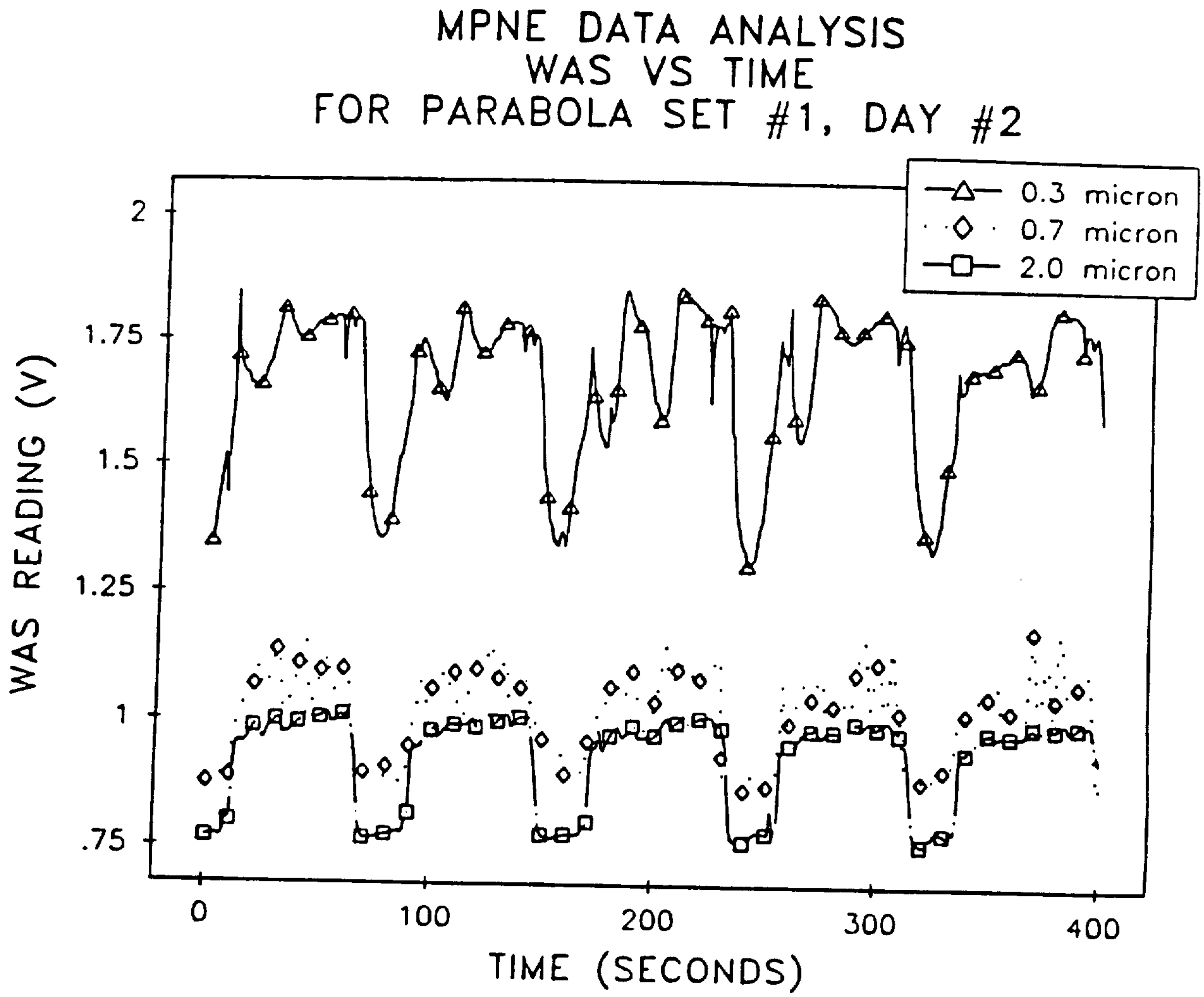


Figure 9. An example of Water Availability Sensor readings versus volume of water added during changing acceleration on the KC-135.

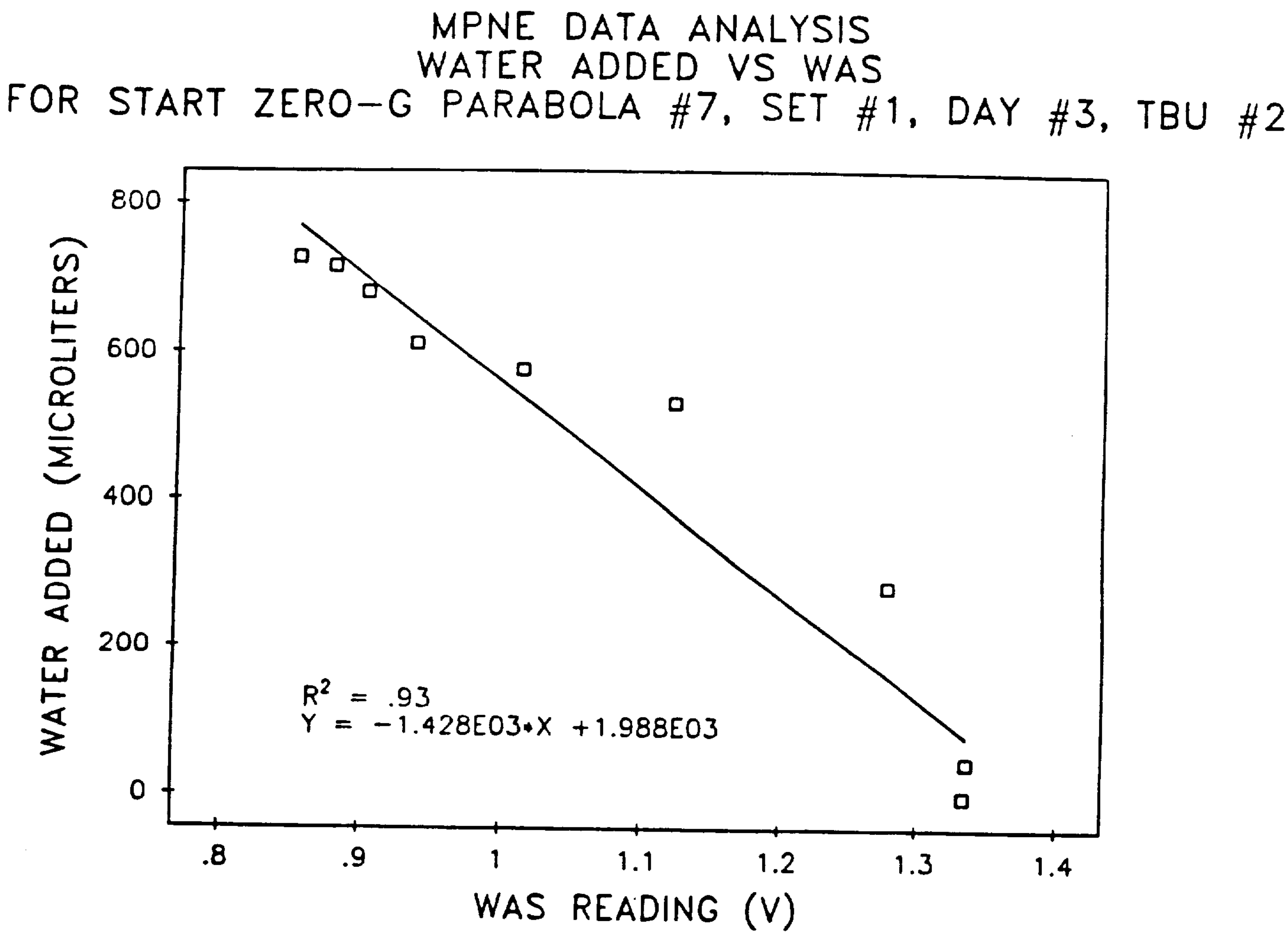
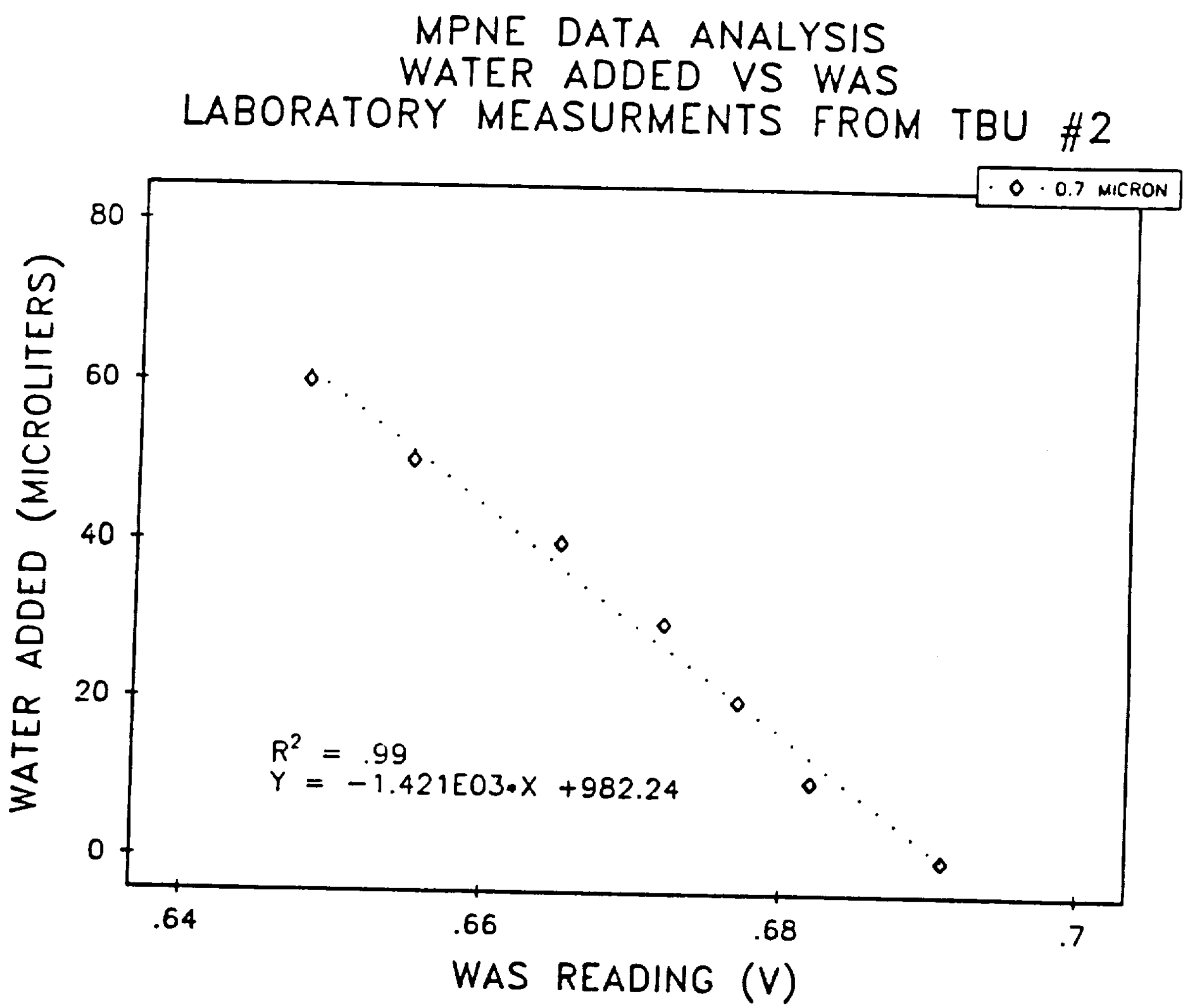


Figure 10. An example of Water Availability Sensor readings versus volume of water added during laboratory measurements (one-g).



controlling moisture sensor on the porous tubes in various acceleration environments. It also shows that the physical control of moisture on the surface of the porous tube has very little dependence on gravity. The principal controlling forces are surface tension, atmospheric pressure and capillary action.

Observations of the Physical Operation of Various Hydroponic Techniques under various acceleration environments:
A large glovebox was flown aboard the KC-135 for the manipulation of fixtures fabricated to simulate various hydroponic techniques under micro-g. These included porous ceramic tubes fixed between two syringes, a porous stainless steel tube fixed between two syringes, two rectangular containers with spray nozzles and syringe pumps similar to an aeroponics system (Dreschel, 1992b), a rectangular container with polyethylene filters and a syringe pump to simulate the Vacuum Operated Nutrient Delivery System or VONDS (Brown et al., 1993) and a porous teflon tubing device for removal of air bubbles from water.

Dry porous ceramic tubes were attached at either end to 60 ml syringes, one full of water, the other empty. The dry tubes were filled by injecting water from the full syringe until weeping occurred, then pulling water through by drawing back the piston from the empty syringe. A mm or more thick layer of water could be maintained on the porous tubes under micro-g conditions. Significant movement in any direction could cause the water to be carried off the surface of the tube. Air could be readily expelled from the dry tube until the inside surface of the tube was saturated. The porous stainless steel tube performed in a similar manner to the porous ceramic tube.

The "aeroponic" containers and the VONDS container demonstrated the large influence of surface tension in the absence of gravity. The water tended either to form into globules and float around inside of the container or adhere to the corners of the container. A considerable amount of shaking motion was required to break the water free from the container corners. Control of the flow of the water was lost as soon as the connection to the fluid loop from the syringe was broken by air entrained in the stream.

The porous teflon tubing tested for use as a phase separation device performed with moderate success. Although the short duration of the period of microgravity did not allow complete separation, some of the air could be expelled from the pores during the transfer of the air-water mixture between the syringes via the porous teflon tubing.

In summary, the TBU's, including the infrared moisture sensor performed well, demonstrating an ability to control wetness on the surface of the porous tubes under various acceleration environments. As expected, water could be held in place readily on the surface of the porous tubes under microgravity because of the hydrophilic nature of the ceramic material. The 0.7 micron pore size tube was chosen for use in the Shuttle flight hardware test because it allowed rapid control of the surface moisture yet has a pore size sufficiently small as to prevent the growth of roots/root hairs into the substrate. The glovebox activities demonstrated what difficulties may be encountered in the various hydroponic techniques examined. These difficulties are mainly due to the fact that in the absence of gravity, surface tension dominates and liquids tend to form stable globules or adhere strongly to surfaces.

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